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Physico-chemical assessment of waters used to irrigate agricultural lands of Amazon

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Abstract

The use of pesticides / fertilizers in plantations has become a problem in maintaining the quality of surface water. Thus, the objective of this study was to evaluate the water quality for irrigation purposes in the Rio Apéu microbasin – Para. The physico-chemical parameters evaluated were: pH, DO, SAR, TDS and EC measured *in situ* and the metals Al, Fe, Na, Ca, Mg determined in the laboratory Evandro Chagas Institute, according to the method of APHA. The average levels of pH (5.51), OD (5.04 mg L^{-1}) are indications of normal condition in Amazonian waters. The results of Al (332 mg L^{-1}) and Fe (5.74 mg L^{-1}) imply the leaching of sediments from the geological formation of the region rich in these minerals, even though they present values above what is recommended by the legislation. The Richard classification allowed us to define that the waters of the study area have low salinity and sodicity, so they are not restricted to use. Thus, the results of the water quality analysis in the watershed can be concluded that it does not offer environmental problems in the use for irrigation activity.

Keywords: Agricultural activity, Irrigation, Water Quality, Surface Water, Castanhal-PA.
Abbreviations: SD_standard deviation, CV_coefficient of variation, PCA_principal component analysis, SAR_sodium adsorption ratio.

Introduction

Irrigated agriculture depends on water availability and good quality, which in turn, is associated with water physical-chemical and microbiological features (Souza et al., 2020). Irrigation can also be hindered by inefficiency and pollution resulting from different water uses, since these parameters can change.

The contamination of aquatic ecosystems results from anthropogenic activities associated with poor management of land, population growth and industrial expansion, which has decreased the quality of water in rivers, lakes and reservoirs (Dupasa et al., 2015, Fia et al., 2015).

In water management, the biggest challenge in a watershed is multiple uses for current and future generations. According to the National Water Agency, irrigation is the sector that consumes the most water in the country. Therefore, the qualitative and quantitative monitoring of water resources in a systematic way is necessary to promote and sensitize their rational use ANA (2015). The predominant use of water defined by the waterbody classification, as well as environmental guidelines for waterbody framing, effluent discharge, qualitative water parameters were set by National Environmental Council, Resolution n. 357, from March 17th, 2005 (CONAMA, 2005).

In a study on the Amazon region, Lathuillière et al. (2016) identified that the best land–water management would be one that intensifies agricultural production by expanding cropland into pasture and considering irrigation, while avoiding conflicts with downstream users and reducing pressure on aquatic ecosystems in the Amazon basin.

The expansion of irrigated crop sites is one of the strategies used to increase agricultural production in Brazil. However, this expansion is limited by water policies focused on restricting water shortage to acceptable levels. Thus, water resource management would help intensifying agricultural production expansion from cultivated lands to pastures, as well as avoiding conflicting water uses for several purposes (Multsch, 2020).

The irrigation-based agricultural practice is of paramount importance due to its socioeconomic and environmental contribution to the Northern region. Although it is sometimes limited by lack of information about water-use efficiency and water pollution (Souza et al., 2012), it remains not affected by water shortage.

The monitoring of water resources and their quality are one of the main actions for carrying out the planning and management, making its application possible. This affects the qualitative characteristics of the water to control environmental conditions (Guedes et al., 2012). It is necessary to monitor water availability and quality to understand the changes that have occurred over time (Carvalho et al., 2020).

Pará State occupies prominent position in the agribusiness scenario, reflecting on irrigated agriculture growth. However, this growth can pose risk to environmental balance, since high water consumption and riparian forest deforestation aim at the construction of water capture structures are the main factors leading to degradation of water courses (Souza et al., 2012).
Irrigation in Iracema Community, Castanhal County, Northeastern Pará State, is based on surface water which is strategic and important tool in agricultural development processes. Thus, it is essential to monitor water resources in the county, since they are potentially used for human, animal consumption, and agricultural activities.
This study aimed at analyzing the quality of surface water used in irrigation activity to correlate with water quality recommendations in the legislation, as well as to assess water sodicity and salinity levels based on Sodium Adsorption Ratio (SAR).

Results and Discussion

Water-quality parameter determination
Results for physical-chemical parameters, Sodium Adsorption Ratio and for values recorded through descriptive statistics such as mean, maximum, minimum, standard deviation and coefficient of variation (Table 1).
CONAMA Resolution n. 357/2005 classified waterbodies as fresh, brackish and saline water of National Territory, based on the quality required for their main uses - distributed into thirteen quality classes. Article 4 of this resolution classifies fresh surface water as belonging to special classes 1, 2, 3 and 4.
Furthermore, art. 42 considers fresh water as class 2, while its respective frameworks are not approved. Therefore, this study adopted parameters belonging to class 2 as reference for fresh surface water use to irrigate vegetables and fruit plants. Table 2 presents physico-chemical parameters of water quality and established reference value (class 2), based on CONAMA Resolution n. 357/2005.
Based on Table 1, mean pH values determined for surface water in F1 and F2 were 5.07 and 5.51, respectively. There was small variation in results recorded throughout the sampled period. The pH values were lower than those allowed by the legislation (Table 2). Rivers crossing the two investigated farms belong to Apeú River watershed and presented acidic features. However, sampled points differed from the existing locations between the farms. Water pH was acidic due to leaching of acidic soils, typical of the Amazon Region, and to the amount of decomposing organic matter forming organic acids at the site.
Piratoba et al. (2017) reported mean pH values ranging from 7.01 (in the rainy season) to 7.39 (in the dry season) in the harbor area of Belém metropolitan region (RMB), PA. On the other hand, Veronez (2011) investigated the water quality of Praquiquara River microbasin (Apeú River tributary) and found values below the limit established by CONAMA Resolution, ranging from 4.2 to 6.8. This range is corroborated with the data in the current study, even in sites far from the urban zone.
Fernandes et al. (2018) observed values indicative of acidic water, which ranged from 5.55 (in Apeú River stretch) to 6.17 (in Macapazinho River). Both rivers also belong to the Apeú River watershed formation, in Castanhal County (Northeastern Para State).
Dissolved oxygen (DO) recorded mean values of 5.04 mg L^{-1} and 4.58 mg L^{-1} for F1 and F2, respectively. There was little dispersion in compliance with standards set by CONAMA resolution n. 357/2005 (Table 2).
However, Apeú River stretch and the river stretch located in Boa Vista Community (which belong to Apeú River watershed) recorded higher DO values - in the order of 14.48 mg L^{-1} and 12.81 mg L^{-1}, respectively. These values may be associated with discharge of raw sewage and of effluents deriving from the open garbage dump in Castanhal County, as reported by Fernandes et al. (2018).
Total dissolved solids (TDS) recorded wide result dispersion. Mean TDS value recorded for water samples collected in F1 and F2 were 174.50 mg L^{-1} and 296 mg L^{-1}, respectively. These values were also in compliance with CONAMA resolution n. 357/2005 (Table 2). TDSs are associated with EC, which is also used to identify water salinity or any anthropic effect capable of affecting waterbodies.
Piratoba et al. (2017) conducted a study in the harbor area of RMB and recorded mean TDS levels ranging from 16.28 mg L^{-1} to 27.05 mg L^{-1} (in the dry season), and from 10.38 mg L^{-1} to 13.35 mg L^{-1} (in the rainy season) in continental water feature. It is known that TDS levels change depending on regional hydrogeochemistry and on the drainage of igneous or sedimentary rocks.
Electrical conductivity is used to measure the total amount of water-soluble salts. Mean values described in the current study were 332.70 µS cm^{-1} (F1) and 325.92 µS cm^{-1} (F2).
Fernandes et al. (2018) conducted a study in Castanhal region during the rainy season and recorded EC of approximately 27.50 µS cm^{-1} in the river crossing the urban stretch and 49.25 µS cm^{-1} in Macapazinho River (Apéu River watershed).
According to Esteves (2011), electrical conductivity in tropical climate regions is associated with climate conditions (rainfall periodicity) and geochemical aspects of the region.
Al, Fe, Ca, Mg and Na concentrations determined in both farms have shown low result dispersion and increased coefficient of variation for Al and Fe concentrations.
Mean Fe content recorded for surface water in F1 and F2 were 0.50 mg L^{-1} and 0.37 mg L^{-1}, respectively. Mean Al concentrations recorded in F1 and F2 were 3.80 mg L^{-1} and 5.74 mg L^{-1}, respectively. None of these values was in compliance with the aforementioned CONAMA resolution.
Barreiras and Pirabas aquifers receive contributions from rocks forming this siliciclastic sedimentary formation – i.e., unconsolidated clay-sandy and sandy-clayey sediments presenting discontinuous ferruginous sandstone levels (Oliveira Filho, 2018). Thus, the likelihood of having Al and Fe contents resulting from minerals composing soil-forming rocks is typical of the geological formation in the region. Iron content in water can cause several environmental issues, as well as in hydraulic installations of the irrigation system.
Only samples collected in January 2019 were influenced by rainfall rates, which rained the day before collection. Results observed for parameters that recorded high values in the dry season, such as TDS, EC, Al and Fe, were not influenced by rainfall rates. However, they featured riparian forest preservation, as well as the conservation of the existing geological formation.
Soil infiltration capacity increased with the higher levels of salinity. On the other hand, it decreased as the sodium adsorption ratio increased and/or as its salinity decreased. Thus, the two parameters - SAR and salinity - must be analyzed together in order to correctly assess the effects of

irrigation water on soil infiltration capacity reduction (Almeida, 2010).
The sodium adsorption ratio reflects the Na^+ ratio to bivalent cations such as Ca^{2+} and Mg^{2+}, whereas the results ranged from 4.53 mmolc L^{-1} to 6.53 mmolc L^{-1} in the river in F1 and from 3.63 mmolc L^{-1} to 7.11 mmolc L^{-1} in the river in F2. Electrical conductivity (EC) results ranged from 15 µS cm^{-1} to 671 µS cm^{-1} in F1, and from 115 µS cm^{-1} to 496 µS cm^{-1} in F2. Table 3 describes the classification of water used for irrigation in the investigated farms.
Based on the methodology described by Almeida (2010), results recorded for mean water variability in the current study were classified as class C1 and C2, low-to-medium salinity, as well as presented low sodicity in all collection months (Table 3). Thus, this water can be used to irrigate sensitive plants grown close to the ground, or in poorly drained soil without restrictions.
However, high salinity/sodicity concentrations in water can affect cultivated sites by inhibiting plants' growth and developmental features. These concentrations can be evaluated based on three different aspects, namely: saline stress based high toxicity levels, accumulation of specific ions and nutritional disorder (Batista, 2016).

Statistical evaluation of water-quality parameters

The correlation set enabled identifying association between variables and emphasizing the trend of the most significant variables for the study. This interaction makes it possible identifying the influence of determining parameters on the quality of the watershed water to be used in the soil.
It is noteworthy that the correlated parameters were similar to the ones analyzed by Lobato et al. (2015), who conducted studies focused on finding new quality indicator (QI) and water quality index (WQI) capable of assessing the quality of the water in the reservoir of a power plant in the Amazon region - they took into consideration specific features of this region.
Pearson's classification was adopted as follows: correlation was perfect positive or negative (r equal to ± 1), strong ($1 > r \geq 0.75$), moderate ($0.75 > r \geq 0.5$), weak ($0.5 > r > 0$) and nonexistent (r = 0). The closer to 1 (whatever the sign), the greater the degree of linear statistical dependence between variables.
Figures 1A and 1B show correlations performed in Pearson's tool (r), based on water quality indicators. Although samples were collected in different periods, different collection day times were not taken into consideration at the time to elaborate correlation data.
Statistical data analysis has shown strong positive correlation between DO and EC/Fe (r = 0.77), between TDS and Salinity/EC (r = 0.89), as well as between Ca and Mg (r = 0.98), Ca and Na (r = 0.82), and Mg and Na (r = 0.81), as shown in Figure 3A. Figure 3B shows strong and positive correlation between TDS and Salinity (r = 0.94), Al and Mg (r = 0.75), Al and Na (r = 0.77), pH and DO (r = 0.75), Mg and Ca (r = 0.83), and Na and Ca (r = 0.75).
The current study has only addressed statistically strong correlations capable of showing the significance of the analyzed data. Data about EC, TDS and salinity have shown strong and positive correlation to each other, which means that the degree of affinity between variables was quite significant. In other words, whenever a given variable presented high correlation to EC, its correlation to TDS and salinity was also high - the same outcome was observed for the correlation between pH and DO.
Variables such as Ca, Mg and Na have shown strong and positive correlation to each other, and this outcome has indicated similar features among these chemical elements.
The positive and strong correlation observed between parameters Al and Mg is explained by their presence in the soil and in minerals forming the watershed. These minerals are transported to waterbodies through leaching process.
Menezes et al. (2016) have investigated soil use/occupation and water quality in an urban watershed, based on Pearson's correlation test. Rates recorded for agricultural sites were positively correlated to DO concentrations and negatively correlated to concentrations in the environmental quality index. Therefore, the influence of human activities on the watershed was observed in the physical-chemical and biological parameters recorded for the assessed water. Forest sites have shown strong correlation to solids concentrations and turbidity, and this finding has indicated native material decomposition.
Overall, highly urbanized watersheds and the ones presenting agricultural sites have been degrading water sources due to changes in conditions of different land-use and occupation types, such as increasing concentrations of water quality parameters, such as nutrients (Fia et al., 2015).
According to Pereira et al. (2016), mapping land use and occupation helps decision-making processes focused on watershed maintenance, territorial planning, and on monitoring the sustainable and legal use of natural resources.
Thus, the current study has emphasized the importance and reliability of the herein addressed experimental treatment and presented the error variance effect. Mean, maximum and minimum values presented the mean variation in the concentration of water quality parameters. Based on Pearson's correlation, most results recorded for the addressed parameters were congruent and presented strong and positive correlation to each other.
Principal component analysis (PCA) is extensively used to identify factors capable of affecting water quality, since it reduces the dimensionality of data sets without losing information. In addition, it explains variations in a large set of correlated variables, based on a small number of principal components (Gradilla-Hernández et al., 2020).
Figures 2A and 2B present PCA application to water quality indicators in order to analyze the surface water in Farms 1 and 2, respectively.
Figure 2A shows the principal component analysis (PCA), which revealed two components capable of explaining 71.91% of total data variability: 44.17% for principal component 1 (PC1) and 27.74% for principal component 2 (PC2).
Principal component analysis has shown two principal components capable of explaining 70.39% of total data variability: 45.35% for principal component 1 (PC1) and 25.04% for principal component 2 (PC2), as shown in Figure 4B.
The first component formed in Figure 2A has explained 44.17% of data variability. Such an association with indicative variables was related to geological action. It happened because Iracema Community is approximately 42 years old; thus, its agricultural activity and distance from the urban zone keep surface water free from anthropogenic interference. Its geogenic origin is the factor best explaining the results recorded for the analyzed parameters.

Table 1. Physical-chemical parameter results recorded for surface water samples.

Collection	Sampling point	Physical-chemical parameters										SAR
		pH	DO*	TDS*	Sal.*	CE **	Al*	Fe*	Ca*	Mg*	Na*	
RIVER – FARM 1												
SEP/18	F1_1	5.30	5.21	242	0.24	485	1.261	0.49	8.04	2.02	13.80	6.15
	F1_2	4.95	5.74	213	0.21	428	0.730	0.99	7.56	1.89	12.49	5.75
	F1_3	5.13	5.32	226	0.08	455	0.744	0.84	6.52	1.72	10.83	5.33
OCT/18	F1_1	5.10	5.36	156	0.15	314	5.209	0.43	7.53	1.76	9.76	4.53
	F1_2	4.92	6.32	128	0.03	389	4.995	0.65	6.87	1.65	10.48	5.07
	F1_3	4.93	5.07	112	0.02	255	6.685	0.39	8.64	2.01	13.41	5.81
NOV/18	F1_1	5.20	4.84	394	0.59	419	3.391	0.43	4.88	1.13	8.72	5.03
	F1_2	5.15	5.49	335	0.33	671	2.783	0.28	4.46	1.05	8.27	4.98
	F1_3	4.81	4.6	266	0.26	535	3.042	0.35	4.62	1.14	8.50	5.01
JAN/19	F1_1	5.35	3.65	6.31	0.01	12.61	6.464	0.34	6.59	1.54	12.49	6.19
	F1_2	5.01	4.39	6.84	0.01	13.65	5.167	0.39	5.81	1.40	11.57	6.09
	F1_3	4.93	4.51	7.60	0.02	15.17	5.083	0.32	7.12	1.72	13.74	6.53
MAXIMO		5.35	6.32	394	0.59	671	6.68	0.99	8.64	2.02	13.80	6.53
MINIMUM		4.81	3.65	6.31	0.01	12.61	0.73	0.28	4.46	1.05	8.27	4.53
MEAN		5.07	5.04	174.40	0.16	332.70	3.80	0.50	6.56	1.59	11.18	5.54
SD		0.16	0.70	128.51	0.17	218.40	2.11	0.22	1.36	0.33	2.05	0.62
CV (%)		3.29	13.91	73.69	108.23	65.64	55.79	44.72	20.78	21.22	18.36	11.36
RIVER – FARM 2												
SEP/18	F2_1	5.99	4.67	247	0.24	496	0.24	0.73	7.16	1.93	10.13	4.75
	F2_2	5.73	5.81	233	0.23	467	3.46	0.22	6.34	1.61	7.23	3.63
	F2_3	5.80	3.45	208	0.20	416	6.49	0.72	8.74	2.14	10.82	4.64
OCT/18	F2_1	5.82	5.65	190	0.18	380	6.16	0.15	7.99	2.14	10.61	4.71
	F2_2	5.73	5.81	233	0.23	467	3.46	0.22	6.34	1.61	7.23	3.63
	F2_3	5.80	3.45	208	0.20	416	6.49	0.72	8.74	2.14	10.82	4.64
NOV/18	F2_1	5.84	5.38	575	0.57	115	3.30	0.21	7.51	1.69	9.96	4.65
	F2_2	4.71	3.87	582	0.58	116	3.98	0.35	7.24	1.60	10.55	5.02
	F2_3	5.52	5.34	597	0.91	179	3.57	0.23	7.06	1.61	10.31	4.95
JAN/19	F2_1	4.69	3.87	204	0.03	406	18.39	0.27	8.28	2.32	14.70	6.39
	F2_2	5.20	4.43	143	0.02	227	6.81	0.21	8.13	1.95	15.63	6.96
	F2_3	5.27	3.17	137	0.02	226	6.44	0.37	8.10	1.92	15.92	7.11
MAXIMUM		5.99	5.81	597	0.91	496	18.39	0.73	8.75	2.32	15.93	7.11
MINIMUM		4.69	3.17	137	0.02	115	0.24	0.15	6.34	1.60	7.239	3.63
MEAN		5.51	4.58	296	0.28	325.92	5.74	0.37	7.64	1.89	11.17	5.09
SD		0.44	1.00	176.96	0.27	142.77	4.44	0.22	0.83	0.26	2.86	1.15
CV (%)		8.06	21.83	59.70	94.78	43.80	77.45	59.85	10.83	13.69	25.64	22.50

Legend: F1 and F2 (Farms 1 and 2). Standard Deviation (SD). Coefficient of Variation (CV) and Sodium Adsorption Ratio (SAR in mmolc L^{-1}). (*) unit in mg L^{-1}. (**) unit in µS cm^{-1}

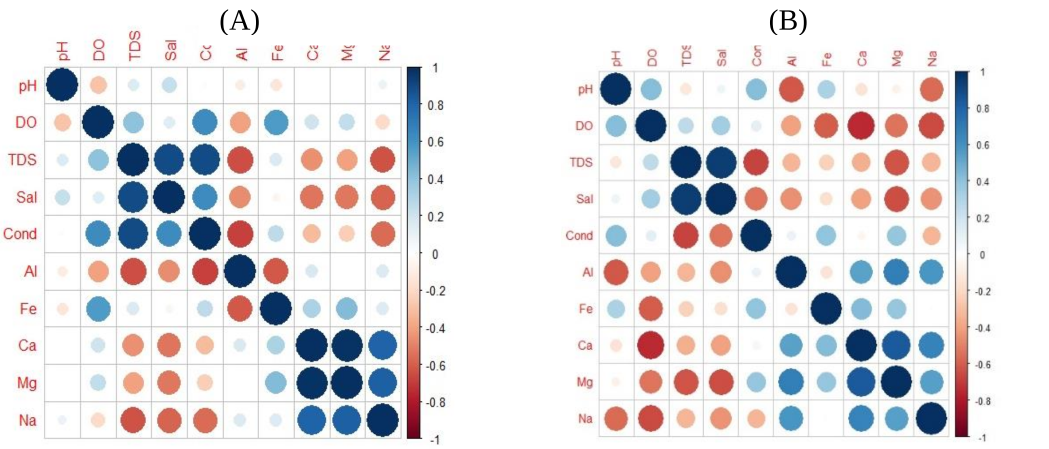

Figure 1 (A). Graph showing correlation between surface water parameters in F1 and (B) Graph showing correlation between surface water parameters in F2. Pearson's correlation was significant at $p < 0.05$.

Table 2. Water quality parameters for class 2.

Parameters	Maximum Allowable Value – MAV
pH	6.0 - 9.0
Dissolved Oxygen (DO)	Not lower than 6 mg L^{-1} O_2
Total Dissolved Solids (TDS)	500 mg L^{-1}
Dissolved iron (Fe)	0.3 mg L^{-1}
Dissolved aluminum (Al)	0.1 mg L^{-1}

Source: CONAMA Resolution n. 357/2005

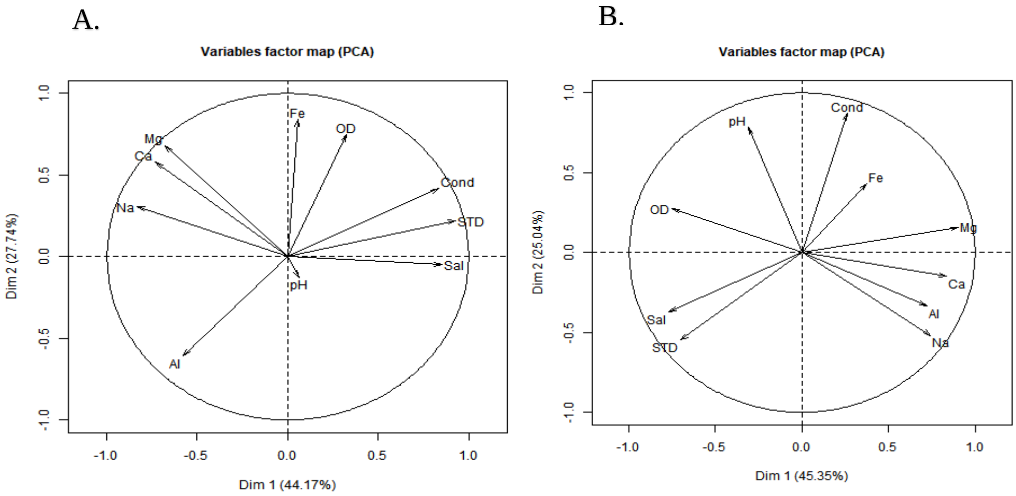

Figure 2. (A) PCA applied to qualitative variables of surface water in farm 1, and (B) PCA applied to qualitative variables of surface water in farm 2.

Table 3. Irrigation water classification, Iracema Community.

Location and Collection	Class	Site and Collection	Class
River_F1 (Sep/18)	C2S1	River_F2 (Sep/18)	C2S1
River_F1 (Oct/18)	C2S1	River_F2 (Oct/18)	C2S1
River_F1 (Nov/18)	C2S1	River_F2 (Nov/18)	C1S1
River_F1 (Jan/19)	C1S1	River_F2 (Jan/19)	C2S1

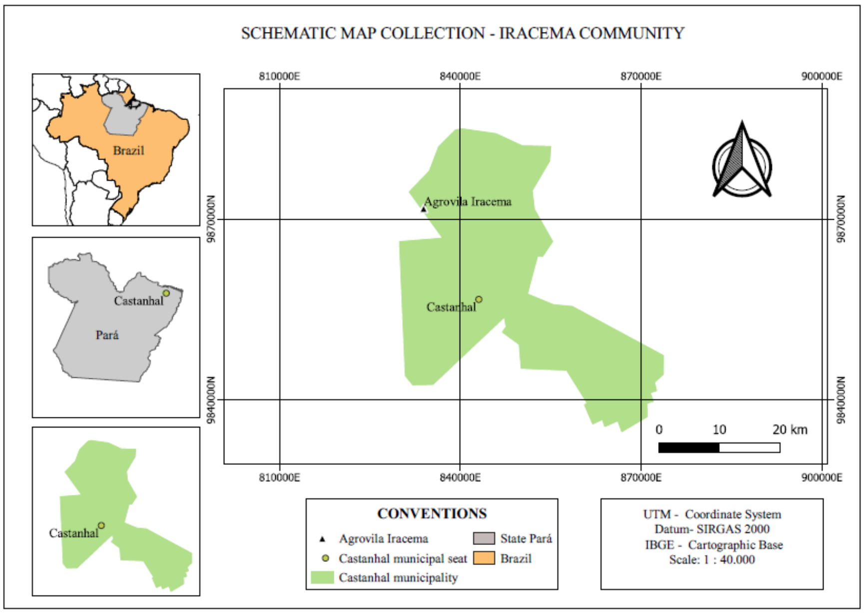

Figure 3. Schematic map of the study area.

Table 4. Description of surface water collection points in Iracema Community.

Collection Points	Description	Geographic Coordinates
F1_01*	Collection performed to the right of the pump installation by taking into account the river current flow.	01°08'8.36"S 48°0'30.37"W
F1_02*	Next to the water-intake pump of the irrigation system	01°08'2.99"S 48°0'43.56"W
F1_03*	Collection performed to the left of the pump installation by taking into account the river current flow.	01°08'2.31"S 48°0'44.96"W
F2_01*	Collection performed to the left of the pump installation by taking into account the river current flow.	01°05'58.83"S 48°0'36.73"W
F2_02*	Next to the water-intake pump of the irrigation system.	01°06'2.05"S 48°0'33.09"W
F2_03*	Collection performed to the right of the pump installation by taking into account the river current flow.	01°06'4.24"S 48°06'29.6"W

Legend: * 01, 02 and 03 correspond to the sampling points of the river.

According to Medeiros et al. (2017), a given variable is strongly associated with a component when its load is greater than 0.7, and reasonably associated with it when its load is greater than 0.5. The two components generated in Figures 2A,B presented strong association with each other.

The first component (44.17% of total variation) was strongly associated with pH and Al. This outcome indicated that these variables were more effective in defining water quality, as well as the Fe/DO group (Figure 2A). With respect to Figure 2B, the first component accounting for 45.35% of total variation has formed two groups: one factor corresponded to variables TDS and Salinity, whereas the other factor was formed by Na, Al, Ca and Mg.

Variables grouped in the first factor were formed by SAR parameters such as Na, Ca and Mg cations, whereas the second factor comprised TDS and salinity, which corroborated the first factor and were the main parameters with relevant eigenvalues correlated to cations of the first factor. It was possible seeing that the most important parameters were the ones associated with soil salinization, which is essential to control and develop different crops.

This multivariate statistical analysis tool (PCA) explains that SAR and salinity are important parameters, used to describe water quality. Positive results recorded for the formed components were significant to assess water use for irrigation purposes.

Based on the visual interpretation of the two-dimensional representation of the first two principal components, there was small dispersion between indicators. According to Medeiros et al. (2017), indicators whose line segment formed smaller angles in relation to Cartesian plane axes were capable of better differentiating sampling points, such as the ones formed by pH and Fe (Figure 2A) and by pH and OD (Figure 2B) in the current study.

Using multivariate statistical analyses such as PCA enabled finding useful correlations to help identifying key issues in the management of integrated water resources, with emphasis on water resource pollution sources (Silva & Gouveia, 2019).

Materials and Methods

Study site

The study was carried out in Iracema Community, Northeastern Para State. It is located 25 km away from Castanhal County, via PA-136 to Km 10 - 15 km to the left side of the road heading towards Castanhal-Santo Antonio do Taua (Figure 3). The local agricultural potential stands out for its perennial crops, vegetable and fruit growing, as well as for poultry breeding under integrated system. Rural properties have good infrastructure to develop these activities: 70.95% of the water supply system comes from artesian wells, and the rest of it comes from rivers and piped water. Thus, approximately 70% of crops grown in the community are irrigated (IBGE, 2019).

Rivers and water courses crossing Iracema community belong to Apeú River watershed, which is located in the intermediate geographical region of Castanhal County and whose area covers 315 km². Approximately 77% of the watershed area belongs to Castanhal County, whereas 16% and 7% of it belong to Santa Isabel do Para and Inhangapi counties, respectively (IBGE, 2019).

Field collection and sampling

Surface water collection took place in two agricultural properties (farms) - called F1 and F2 – located at the following geographical coordinates: 01°07'19.4 ”S and 48°01’48.2”W; 01°06’04.3”S and 48°06’29.6” W, respectively (Figure 3) - sampling points are described in Table 4.

Water sampling was carried out on a monthly basis from September to November 2018, which corresponded to the lowest rainfall period, as well as in January 2019, which corresponded to the highest rainfall period. Collections carried out from September to November recorded mean rainfall rate of approximately 75 mm (2018), whereas the one carried out in January (2019) recorded mean rainfall rate of 321 mm (INMET, 2019).

Water collection took into consideration the place where the water-intake pump used in the irrigation system was installed, since collection points were located approximately 500 m apart from both sides of the pump. Sample collection and preservation procedures were based on the National Guide for the collection and preservation of water, sediment, aquatic community and liquid effluent samples (CETESB, 2011).

Physico-chemical analysis

The analyzed parameters were pH, Dissolved Oxygen (DO), Salinity (Sal.), total dissolved solids (TDS) and electrical conductivity (EC). They were measured *in loco* with the aid of portable multiparameter water quality meter (BANTE Instruments, model Bante900P), which was properly calibrated, based on standards set by the American Public Health Association - APHA (2012).

Metal determination
The concentration of metals such as Aluminum (Al), Iron (Fe), Calcium (Ca), Magnesium (Mg) and Sodium (Na) in the samples was determined through filtration and acidification procedure based on nitric acid with high degree of purity (HNO_3), pH < 2. Metals were analyzed through Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES), in Vista-MPX CCD model equipment. Detection limits of the equipment were Al (0.0122 mg L^{-1}), Fe (0.045 mg L^{-1}), Na (0.0242 mg L^{-1}), Ca (0.0240 mg L^{-1}) and Mg (0.0002 mg L^{-1}). Reference sample for trace elements in water (SRM 1643e, Trace Elements in Water, NIST, USA) was used for result certification purposes. Recovery values ranged from 90% to 105%, which validated analyses carried out at the Toxicology Laboratory of Evandro Chagas Institute and were in compliance with the Standard Methods for the Examination of Water and Wastewater (APHA, 2012).

Sodium adsorption ratio - SAR
Water classification criteria suggested by the United States Salinity Laboratory (USSL) is one of the most accepted for irrigation purposes. This classification is based on sodium adsorption ratio and on water electrical conductivity.
SAR indicates the sodium rate in a given sample that can be absorbed by a given soil. According to Queiros (2018), SAR is calculated through equation 1, based on data about Ca^{2+}, Na^{2+} and Mg^{2+}, which are transformed from mg L^{-1} to meq L^{-1} and are numerically equal to mmolc L^{-1}.

$$SAR = \frac{Na}{\left(\frac{Ca + Mg}{2}\right)^{0.5}} \qquad \text{Eq. 1}$$

Wherein:
Ca: calcium concentration, mmolc L^{-1};
Na: sodium concentration, mmolc L^{-1};
Mg: magnesium concentration, mmolc L^{-1}; and
SAR: Sodium Adsorption Ratio (mmolc $L^{-1})^{0.5}$

Statistical analysis
Descriptive statistics was used to systematize the results - mean, minimum, maximum, standard deviation and coefficient of variation were tabulated. Pearson's correlation coefficient (r) was used to measure the degree of linear correlation between two quantitative variables and could range from -1 to 1. The sign before the number was used to indicate whether the direction was positive or negative, whereas the value indicated the strength of association between variables (Montgomery, 2004). The tabulation of descriptive statistics results and correlation graph plotting to explain the interaction between parameters were carried out in Statistica® software version 3.6.
A 12x10 matrix (twelve observations and ten key parameters) was generated to help interpreting multivariate statistics. Exploratory principal component analysis (PCA) was used to better understand the contribution of each water quality parameter to the observed variability (Gumbo et al., 2016). It was necessary standardizing the analyzed data before PCA, due to their dimensional differences. It was done through the z-score standardization function. Statistical analyses were performed in Statistica® software version 3.6.

Conclusion

Lower pH values with acidic features were observed among the evaluated water quality parameters. Such an outcome can account for corrosivity in the water, and lead to the deterioration of irrigation system pipes. Low DO and EC values were in compliance with recommendations by CONAMA resolution.
Al and Fe concentrations higher than that recommended by CONAMA resolution n. 357/2005 in the sampling points is explained by the local geological formation. However, attention should be given to the likelihood of future issues such as irrigation equipment efficiency loss, since these elements can clog pipes, reduce emitters' flow, link to other metals and work as sediment transport or deposition medium.
Sodium adsorption ratio did not show restrictions to water using for irrigation purposes, since the investigated watershed area remains free from major anthropogenic interference.
Statistical treatments worked as tool to helped better understanding the results and to assist decision-making processes focused on monitoring water quality in the assessed region based on rational water-using management.

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References

Agência Nacional de Águas ANA (2015) Conjuntura dos recursos hídricos no Brasil, Informe 2015, Brasília, 88.
American Public Health Association APHA (2012) Standard Methods for the Examination of Water and Wastewater, 22nd Ed. Washington DC.
Almeida OA (2010) Qualidade da água de irrigação. Dados Eletrônicos. Cruz das Almas: Embrapa Mandioca e Fruticultura.
Batista PHD, Feitosa AK, Leite FE, Sales MM, Silva KB (2016) Avaliação da qualidade das águas dos rios São Francisco e Jaguaribe para fins de irrigação. Rev Agropec Cien no Semiarido, 12(1): 48-54.
Carvalho LLS, Lacerda CF, Lopes FB, Andrade, EM, Carvalho CM, Silva SL (2020) Caracterização dos usos das águas subterrâneas no perímetro irrigado do Baixo Acaraú – Ce. Rev Agro Amb. 12(1): 249-271.
Companhia de Tecnologia de Saneamento Ambiental (2011) Guia nacional de coleta e preservação de amostras: água, sedimento, comunidades aquáticas e efluentes líquidos. Companhia Ambiental do Estado de São Paulo. Brasília: CETESB - ANA.
CONAMA n.º 357, de 17 de março de 2005. Conselho Nacional de Meio Ambiente. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para seu enquadramento, bem como, estabelece as condições e padrões de lançamento de efluentes, e dá outras providências. Brasília: Diário oficial da União.
Esteves F (2011). Fundamentos de limnologia. 3. ed. Rio de Janeiro: Interciência.
Fernandes FPS, Gonçalves JD, Brígida FVS, Oliveira LS, Pedroso AJS (2018) Parâmetros físicos e químicos das águas superficiais de três corpos hídricos situados na cidade de Castanhal-PA. In: III Congresso Internacional das Ciências Agrárias. COINTER. Castanhal-PA.

Fia R, Tadeu HC, Menezes JPC, Fia FRL, Oliveira LFC (2015) Qualidade da água de um ecossistema lótico urbano. Rev Bras de Rec Hídric. 20(1): 267-275.

Gradilla-Hernández MS, de Anda J, García-González A, Meza-Rodríguez D, Montes CY, Prefecto-Ávalos Y (2020) Multivariate water quality analysis of Lake Cajititlán, Mexico. Env Monit and Assess. 192(1): 5.

Gumbo JR, Dzaga, RA, Nethengwe, NS (2016) Impact on water quality of Nandoni water reservoir downstream of municipal sewage plants in Vhembe District, South Africa. Sustainability. 8(7): 597.

Instituto Brasileiro de Geografia e Estatística - IBGE. Censo 2019. Rio de Janeiro. Retrieved December, 2019, from http://www.ibge.gov.br

Instituto Nacional de Meteorologia – INMET. Monitoramento Automático das Estações. Brasília. Retrieved December, 2019, from http://www.inmet.gov.br

Lobato TC, Hauser-Davis RA, Oliveira TF, Silveira AM, Silva HAN, Tavares MRM, Saraiva ACF (2015) Construction of a novel water quality index and quality indicator for reservoir water quality evaluation: A case study in the Amazon region. J of Hydrol. 522, 674–683.

Lathuillière MJ, Coe MT, Johnson MS (2016) A review of green- and blue-water resources and their trade-offs for future agricultural production in the Amazon Basin: what could irrigated agriculture mean for Amazonia. Hydrol Earth Syst Sci. 20, 2179–2194.

Medeiros GA, Tresmondi ACCL, Queiroz BPV, Fengler FH, Rosa AH, Fialho JM, Lopes RS, Negro CV, Santos LF, Ribeiro AI (2017) Water quality, pollutant loads, and multivariate analysis of the effects of sewage discharges into urban streams of Southeast Brazil. Energy: Ecol and Environ. 2(4): 259-76.

Menezes JPC, Bittencourt RP, Farias MS, Bello IP, Fia R, Oliveira LFC (2016) Relação entre padrões de uso e ocupação do solo e qualidade da água em uma bacia hidrográfica urbana. Rev Eng Sanit e Amb. 21(3): 519-534.

Montgomery DC, Runger GC, Hubele NF (2004) Estatística Aplicada à Engenharia, 2ª. ed., LTC: Rio de Janeiro.

Multsch S, Krol MS, Pahlow M, Assunção ALC, Barretto AGOP, Lier QJV, Breuer L (2020) Assessment of potential implications of agricultural irrigation policy on surface water scarcity in Brazil. Hidrol Earth Syst Sci. 24, 307–324.

Oliveira Filho OBQ, Galarza Toro MA, Silva WCM (2018) Caracterização hidrogeoquímica dos sistemas aquíferos barreiras e Pirabas da região metropolitana de Belém (RMB) e investigação de Possíveis misturas entre as águas. Caderno de Geociênc. 14(1-2): 8-23.

Pereira BWF, Maciel MNM, Oliveira FA, Alves MAMS, Ribeiro AM, Ferreira BM, Ribeiro EGP (2016) Uso da terra e degradação na qualidade da água na bacia hidrográfica do rio Peixe-Boi, PA, Brasil. Rev Amb e Água. 11(2): 472-485.

Piratoba ARA, Ribeiro HMC, Morales GP, Gonçalves WG (2017) Caracterização de parâmetros de qualidade da água na área portuária de Barcarena, PA, Brasil. Rev Amb e Água. 12(3): 435-456.

Queiroz TM, Melo MT, Ferreira FS (2018) Qualidade da água para irrigação na comunidade quilombola Vão Grande, município de Barra do Bugres/MT. Rev Bras de Agric. 12(3): 2613-2620.

Silva COF, Gouveia D (2019) Avaliação da qualidade ambiental de corpos hídricos urbanos utilizando análise multivariada. Rev Interações. 20(3): 947-958.

SOUZA CA, QUEIROZ TM (2020) Qualidade água na bacia hidrográfica do Rio das Garças/MT para fins de irrigação. Rev Ib de Ciênc Amb. 11(1): 157-164,

Souza RORM, Pantoja AV, Amaral MACM, Neto JAP (2012) Cenário da agricultura irrigada no estado do Pará. Rev. Irriga. 17(2): 177-188.

Veronez BP (2011) Análise da influência da precipitação pluviométrica e do uso do solo sobre a qualidade da água em microbacia hidrográficas no nordeste paraense, Amazônia Oriental. Dissertação de Mestrado. Universidade Federal do Espírito Santo, Vitória, ES, Brasil. 172.